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A DECISION MODEL FOR PREDICTING THE

COST OF ALUMINUM AIRFRAME

DETAIL PARTS

A THESIS

Presented to

the Faculty of the Graduate Division

by

Donald Leslie Spanton

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

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Approved:

Date Approved by Chairman:

May 28, 1958

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Among the many criteria used in making industrial decisions cost is one of the most prominent. The optimization of cost is a goal of all industrial organizations. The measure of success in achieving this optimum cost is dependent upon many factors, one of which, methods of manufacturing, is examined in this thesis.

Forty-one 7075 - T6 aluminum alloy detail machined parts comprise the sample analyzed. These parts are manufactured by one of the following methods:

(1) Gross forging cleaned up by conventional milling,

(2) Gross forging cleaned up by numerically controlled milling and conventional milling,

(3) Plate stock machined by numerically controlled milling.

The specific purpose of this investigation is to develop a model which will predict the cost of a detail part made by one of these three methods of manufacture. It is assumed that cost is the only criterion and that the functional requirements of the part can be met by any of the three methods. The development of such a model will permit the objective selection of the method which will result in optimum cost.

Since few manufacturers of finished machined parts have the facilities to mine and process raw material prior to the actual machining operation, total cost of a detail part can be divided into two categories, "in-plant" cost and "out-of-plant" cost. Use of

this terminology permits manufacturers who do not procure material from another company but rather obtain material from another division of their own company to apply this model.

Since this model is to be used as an effective predictor, it must use information which is available early in the design life of the detail part. Therefore, five independent variables, obtainable from an engineering drawing, are used to estimate the number of "in-plant" hours, which, when multiplied by an average wage rate, will yield the "in-plant" cost. These same "in-plant" hours, which are an indication of the part complexity, are used to estimate the "out-of-plant" cost. The sum of the "in-plant" cost and the "out-of-plant" cost is taken as the total cost.

In this investigation, an IBM 704 general purpose digital computer is used to solve the simultaneous equations necessary to obtain the regression coefficients of the equation used in predicting the "in-plant" hours. The computer is also used to produce the three expressions used to estimate the "out-of-plant" cost for the three methods of manufacture. These expressions are produced using the method of "least-squares" taking the actual "in-plant" hours as the independent variable and actual "out-of-plant" costs, historical information obtained from Purchasing Division records, as the dependent variable.

The test of each of the resultant expressions is a correlation analysis. The correlation coefficients of these analyses indicate that this approach to model development can be used satisfactorily.

CHAPTER I

INTRODUCTION

How to achieve optimum cost? This is a constant question in the minds of industrial executives. Often unsatisfactorily answered, the question is directed into many fields such as purchasing, transportation, promotion, merchandising, and production. In order for true "optimum" cost to be achieved, the proper decisions must be reached in each of the mentioned areas. Although none of these decisions can be arrived at with complete independence, there are some which can presently only be approached by separate analysis. One of these, manufacturing (or production), has been selected for closer scrutiny.

More specifically, it is observed that there exists a need for a decision model which could be used to adequately predict the cost of a single unit produced by various available manufacturing methods. If cost is the only criterion, it is assumed that the method of lowest cost would be optimum.

Confusion about the lowest cost method of manufacture has been nurtured by several things. It is paradoxical that technological advancement has created much of this confusion. The development of machine tools for unique operations has permitted great reductions in cost of these particular operations. However, these operations were formerly done on some machine which was of a more general-purpose nature. Since the older equipment is not necessarily entirely obsolete (or completely amortized), it is often retained. This retention may be justified by reasoning that it provides "flexibility" in the plant. Thus, over a period of time several methods to do similar operations may be available, thus adding to the difficulty in deciding which one is to be used.

A simple example will serve to illustrate. In fabricating sheet metal, three general operations may be performed: blanking, forming, and profiling. If, in a given plant at a given time, the number of available methods for each of these three operations is five, ten, and eight, respectively, the available alternate routes total 1771. By increasing the number of methods only one in each area, the number of available alternate routes for one piece of material becomes 2600!

In a large organization where the "planning" and the "doing" of the work is separated, the addition of new machine tools may become a liability. Personnel who plan work will have a general tendency to continue to route work to those machines with which they are most familiar. If an effective educational program is carried out too many people may route work to the new machine thus exceeding its capacity. In either case the "flexibility" of the shop is reduced, problems of transportation and production control are multiplied, costly revisions of paper work occur, delays increase, and costs rise.

Knowing that these problems exist, people who have the responsibility of deciding on the best method of manufacture are sometimes in conflict on how to resolve them. Again, using cost as the only criterion, a cost analysis would seem to be the best approach to solving this problem. Yet to perform a detailed cost analysis on every part may not be feasible. Hence, a predictor is desirable.

It is the purpose of this investigation to analyze a sample of detail aluminum airframe parts, manufactured by one of three different available methods, in an effort to develop such a predictor. A detail part is complete in itself in contrast to an assembly part which consists of two or more detail parts joined together. Airframe parts are those which are structural members of an aircraft rather than equipment or accessory components such as hydraulic tubing, control cables, wire harnesses, etc. All of the considered detail parts are machined. Each of the detail parts in the sample is included in one of the following groups:

(1) Gross forgings which are cleaned up by conventional milling,

(2) Gross forgings which are cleaned up by numerically controlled milling in addition to conventional milling,

(3) Plate stock machined by numerically controlled milling.

Each of these three groups represents a different method of manufacture. The variety of conventional manually controlled milling machines available has been increasing constantly. Numerically controlled milling, as shown in Fig. 1, although relatively new, is becoming more widely accepted and adapted. Its use, however, may be questioned by those unfamiliar with its capabilities and the resulting conflict of opinion is difficult to resolve. The nature of this conflict usually is concerned with cost.

In general, less tooling is required for numerically controlled milling than conventional milling. In addition, if the functional requirements of the part can be met by plate stock, not only is the cost

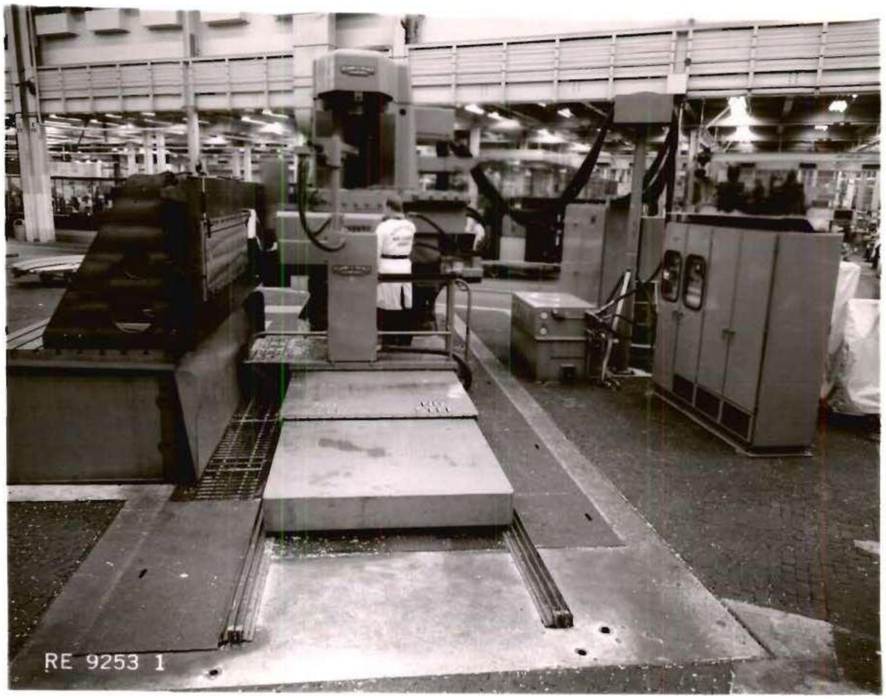


Fig. 1

Kearney and Trecker Numerically Controlled

Milling Machine with Bendix Tape

Control Unit

of material far less for plate stock than for a gross forging but the procurement and delivery time is considerably less. Yet it is argued that, for certain rates of production, machining a gross forging would result in lower cost. If a gross forging is deemed necessary there is still the question of how it can be most economically machined to its net dimensions. A decision model to predict relative cost would help resolve this conflict.

To be of use to management, this decision model would have to take advantage of information that was available immediately upon completion of the detail part design. Such information would be found on an engineering drawing. If selected information could predict the number of hours which would be expended in the plant, this would save the time and cost of a detailed analysis. Such an analysis at present includes developing the standard hours using synthetic times, planning the family of tools required to produce the part, and estimating the hours to design and build these tools. The estimated number of hours times an average wage rate would be an indication of the "in-plant" direct cost.

In addition to the "in-plant" cost, some estimate of the charges payable to vendors for materials would be required. This "out-of-plant" cost could be for plate stock or for gross forgings. Since special tooling is not required to produce plate stock, this cost can be quickly obtained knowing only the alloy, thickness, and quantity of material required. However, when gross forgings are required, the cost of forging dies must be ascertained in addition to the estimated cost per piece. At present this is done by soliciting quotations from several vendors, who estimate their die costs from an engineering drawing. Obtaining these quotations is often a lengthy process. Therefore, if the predictor used in estimating the "in-plant" cost could be adapted to estimate the "out-of-plant" cost, valuable time could be saved.

It is hypothesized that a decision model for predicting the cost of aluminum airframe detail parts can be developed. This model will use initial engineering information to predict the "in-plant" cost and the "out-of-plant" cost, the sum of which will be considered the total cost. Because of the great difference in the requirements of tooling for detail parts made from plate stock and forgings, it is assumed that expressions containing different constants for each method of manufacture will result. With cost as the only criterion, the lowest estimated total cost will indicate the optimum method of manufacture.

The initial engineering information analyzed will be selected from engineering drawings of detail parts on the basis of observations and previous experience. It is felt that the number of planes in which machining is done, the number of dimensions required to adequately define the part, the number of different non-hole radii, the number of holes, and the number of different hole radii would be five variables which could significantly affect the total time required to design and build tools and produce a finished detail part from either plate stock or a gross forging. For the sample data collected a regression equation will be developed using these five variables as the independent variables and the actual hours as the dependent variable since the hours multiplied by an assumed average wage rate will yield the "in-plant" cost.

To determine the "out-of-plant" cost, the sample will be separated into three sub-classes, one for each method of manufacture under consideration. Within each sub-class, the method of least squares will be used to obtain an expression to predict the actual "out-of-plant" cost from the actual hours.

The test of each of the expressions in the developed model will be a correlation analysis comparing predicted and actual values.

A literature survey indicated a general lack of specific criteria to select the method of optimum cost when more than one method of manufacture is available. Comments of a general nature are fairly prevalent. Bolz (1) states that ". . . the general design characteristics and quantity requirements of specific machine parts can usually be expected to place them in a well defined production category." Baldwin and Niebel (2) make statements such as: "Decisions are being made constantly between two or more processes," and "An engineer naturally will tend to select materials and processes with which he is familiar," but do not indicate specifically on what basis these decisions and selections are being made. Mooney (3) very adequately discusses the quantity of work involved in a well performed producibility study, yet does not attempt to supply a general expression which could be used to predict cost. Nordhoff (4) states that "After an estimator has satisfied himself on what machine an operation is to be performed . . ." yet makes no mention as to how this decision is reached. It is implied in these statements that where the best method is not "obvious" experience of the individual will be used in selecting the best method of manufacture.

These and similar statements were made prior to the introduction of numerically controlled milling. Although efforts of one of the principle organizations in this field, the MIT Servomechanisms Laboratory, have been directed primarily at research and development, an economic study by Gregory and Atwater (5) was performed. Their results indicate that some types of work would still be done at less cost by means other than numerically controlled milling. Although Dahl (6) mentions some of the advantages and disadvantages of numerical control he does not suggest how cost decisions should be made in determining which parts are to be made using this new machine tool. Current magazine literature contains many case histories and success stories about the use of numerical control but these tell of estimated cost savings _after_ the work is done. At present, a decision model to _predict_ cost in advance does not seem to exist.

CHAPTER II

EXPERIMENTAL ENVIRONMENT AND DATA COLLECTION

Each of the manufactured parts under investigation is used in the manufacture of the C-130 HERCULES prop-jet transport built by Lockheed Aircraft Corporation, Marietta, Georgia. Further, all of the parts have three things in common, alloy, machined surface requirements, and minimum dimensional tolerance. The aluminum alloy selected was 7075-T6 which has properties as shown in Appendix VI. The most critical machined surface requirements on all sample parts was 250 rms. The most critical dimensional tolerance, other than hole diameter, was ±.010 inches. Within the plant itself, six specific sources were used in obtaining the various items of information to be included in the sample data. They were: (1) the production machine shop, (2) engineering drawings, (3) operation sheets, (4) tabulated budget reports, (5) the Purchasing Division price files, and (6) the Master Record Tool Control files.

Production Machine Shop

Since almost all information is recorded by part number, the first step taken in collecting the data was to obtain a sample of part numbers of machined detail parts. In an effort to make this a random sample, the detail part numbers were selected by actually observing the lots of material and gross forgings being processed in the production machine shop. During the period in which the data was collected, the normal shop-span for a lot of material was 25 working days or five weeks. Therefore, the observed part numbers were obtained on each Wednesday of five successive weeks to assure selection of parts over the entire span. It was arbitrarily decided to attempt to include 50 detail parts in the sample. Since it was highly probable that not all information would be available for all parts, 60 part numbers were initially recorded, 12 each week.

Engineering Drawings

After the list of 60 part numbers was recorded, the next step was to obtain an engineering drawing for each part. These drawings, or blueprints as they are often called, contained all of the information that would be required to use the proposed model. On each drawing a manual count was made of the five independent variables used in the investigation. As shown in Appendix IIA these were:

(X_2) The number of planes in which machining was done

(X_3) The number of dimensions on the face of the drawing

(X_4) The number of different external (non-hole) radii

(X_5) The number of holes in the part

(X_6) The number of different internal (hole) radii.

Operation Sheets

The third step in collecting the data was to obtain operation sheets for each of the 60 detail parts. As the title implies, this form contains operational instructions for production personnel. It enumerates the sequence of operations and the specific equipment or machine tools on which the operations are to be performed. It completely identifies the material and the detail part number. Space is provided for various agencies to apply rubber stamp approvals signifying the progressive completion of work.

There were several specific items of information obtained from the operation sheets. One of these items was the total standard hours required to produce each part. Another item was a list of the project tools required to complete each part.[1] Also a list of typical machine tools used for conventional milling was compiled, some of which are shown in Appendix VII.

Tabulated Budget Reports

The next step in collecting information used in developing the model was to obtain the hours expended in designing and making the project tools associated with each of the parts in the sample. These hours, divided by estimated number of parts, were added to the total standard hours per part to obtain the dependent variable, X_1, the total actual "in-plant" hours. This information is published periodically for purposes of budget control and forecast. Listed by part number are the hours spent, as recorded by Timekeeping, by the Tool Design department and the Tool Manufacturing Division for each project tool associated with that part number. Using the list of project tools for each part obtained from the operation sheets as a guide, it was recognized that complete information on all parts was not available. As a result,

---

[1]Project tools are those required for the production of a unique part and generally can be used for one part <u>only</u>. Examples of project tools are templates, mill fixtures, drill fixtures, etc.

12 part numbers were lost from the initial sample of 60, leaving a total of 48.

Purchasing Division Price Files

The fifth step in collecting data was the recording of costs paid to vendors for purchased plate stock and gross forgings. The price files of the Purchasing Division yielded this historical information. By recording the number of pieces and the price per piece over the history of the forging as shown on price record cards, the average cost per piece was obtained. In addition, the cost of the forging dies was obtained. A current pricing schedule for plate stock, shown in Appendix IV, was used to establish the price per piece for those detail parts made from plate stock. For information purposes only, the geographical location of several vendors was noted so that sample transportation costs could be shown as listed in Appendix V. Because of the long period of time covered by these files, the resulting incomplete information caused the loss of seven more part numbers from the initial sample, leaving 41 as the final sample size.

Master Record Tool Control Files

The sixth and final step in collecting the data was accomplished by checking the Master Records Tool Control files. In these files are contained all original tool orders, both for tool design and tool make. By examining the orders for the original "make new" tools for the 41 parts included in the sample, it was possible to obtain the estimated number of parts which were expected to be made at the time the order was written. This estimated design life of the part was necessary for use in subsequent computations.

CHAPTER III

PROCEDURE AND DATA ANALYSIS

As mentioned in Chapter I, the approach used in the development of this model had to start by obtaining some means of predicting the "in-plant" hours. After the data on the 41 machined detail parts was collected, the six mentioned variables were subjected to a multiple correlation analysis. Rough scatter diagrams, one of which is shown in Fig. 2, of each independent variable against the dependent variable indicated that the data could be considered linear for the purpose of the analysis.

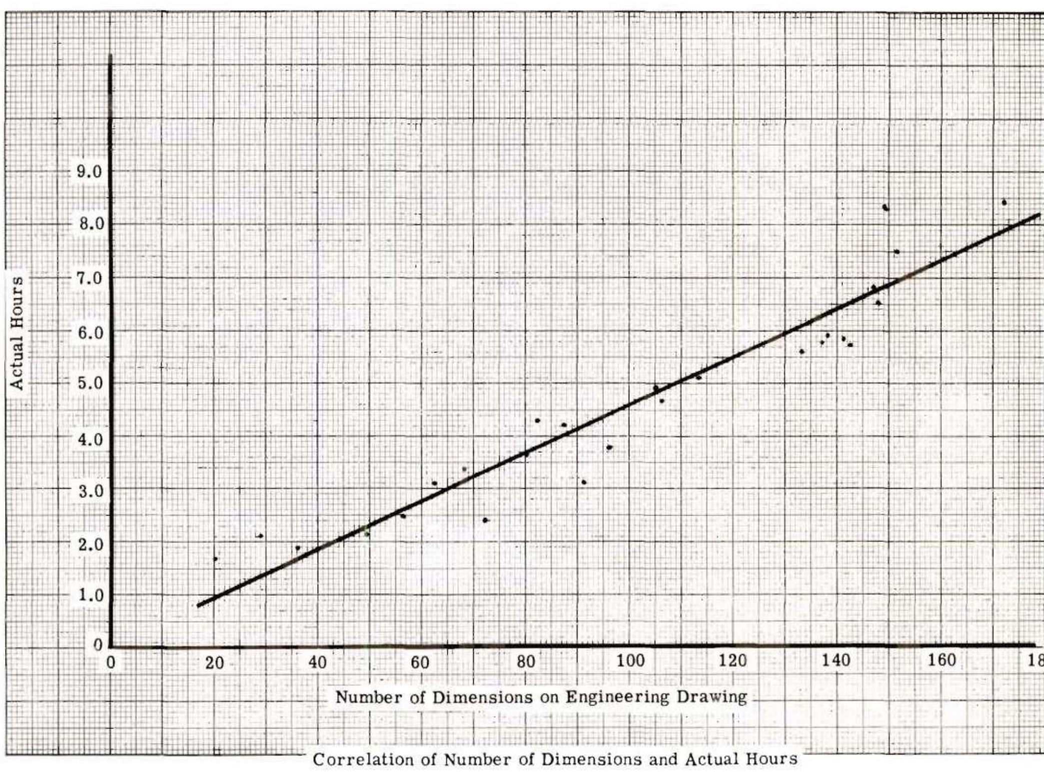


Fig. 2

Using the method and notation of Ezekiel (7), the sums, squares, sums of squares, products, and sums of products of all variables were obtained as shown in Table 1 of Appendix IIA. This was followed by the development of the six equations as shown in Appendix IIIC.

To solve the five simultaneous equations necessary to obtain the partial regression coefficients would have been difficult and tedious. Therefore, an IBM 704 general purpose digital computer was used at this point of the data analysis. The standard computer routine required only the system matrix in punched card form as input data.

Once the partial regression coefficients were obtained and the constant of the regression equation established, two things were done. The multiple correlation coefficient of the dependent variable with respect to the five independent variables was obtained. Also, the regression equation was used to estimate the "in-plant" hours for each of the 41 detail parts included in the sample. The correlation coefficient of actual "in-plant" hours and estimated "in-plant" hours was then obtained as shown in Appendix IIID. The significance of the multiple correlation coefficient was indicated by using the procedure of Kendall (8) to obtain a Z value for comparison with a table of values of the Z distribution at the one per cent level as shown in Appendix IIIC.

Next, the sample of 41 detail parts was broken down into three sub-classes, one for each method of manufacture under consideration. Group one, containing 25 parts, represented gross forgings machined by manually controlled milling. Group two, containing nine parts, represented gross forgings machined by numerically controlled milling and manually controlled milling. Group three, containing seven parts, represented plate stock machined by numerically controlled milling.

The "out-of-plant" cost per piece was found for each detail part as shown in Appendix IV. Then, using a standard "least-squares" computer routine, the first, second, and third order expressions were obtained for each of the three sub-classes of data considering the "in-plant" hours as the independent variable and the "out-of-plant" cost as the dependent variable. In addition, similar expressions were obtained using the natural logs of each variable. Of the resulting 18 expressions, three predictor equations were selected which produced the best fit when the relatively small sample size was considered. These three equations were used to predict the "out-of-plant" cost used to obtain the correlation coefficient of actual "out-of-plant" cost and estimated "out-of-plant" cost as shown in Appendix IIIE.

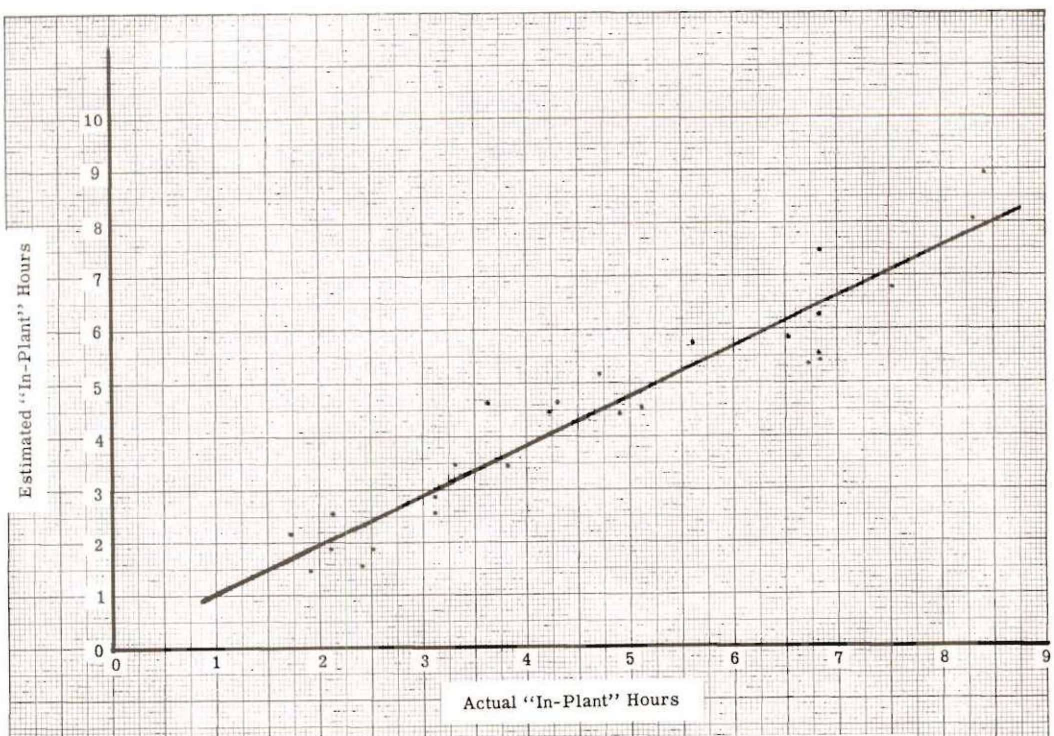
To obtain the actual total cost, the actual "in-plant" cost, which was the actual "in-plant" hours multiplied by an assumed hourly wage rate of $2.50, was added to the actual "out-of-plant" cost. To obtain the estimated total cost, the estimated "in-plant" cost, which was the estimated "in-plant" hours multiplied by the same wage rate ($2.50), was added to the estimated "out-of-plant" cost obtained through the use of the three predictor equations. A correlation coefficient for actual total cost and estimated total cost was obtained as shown in Appendix IIIF.

CHAPTER IV

DISCUSSION OF RESULTS

The results of this investigation indicate that conclusions to the hypothesis are affirmative. Each of the phases of the investigation are summarized below while the computations are shown in detail in the appendices.

The multiple correlation coefficient, corrected for sample size, is .900, indicating the five independent variables considered can be used to estimate the "in-plant" hours. After using the regression



Correlation of Estimated "In-Plant" Hours and Actual "In-Plant" Hours

Fig. 3

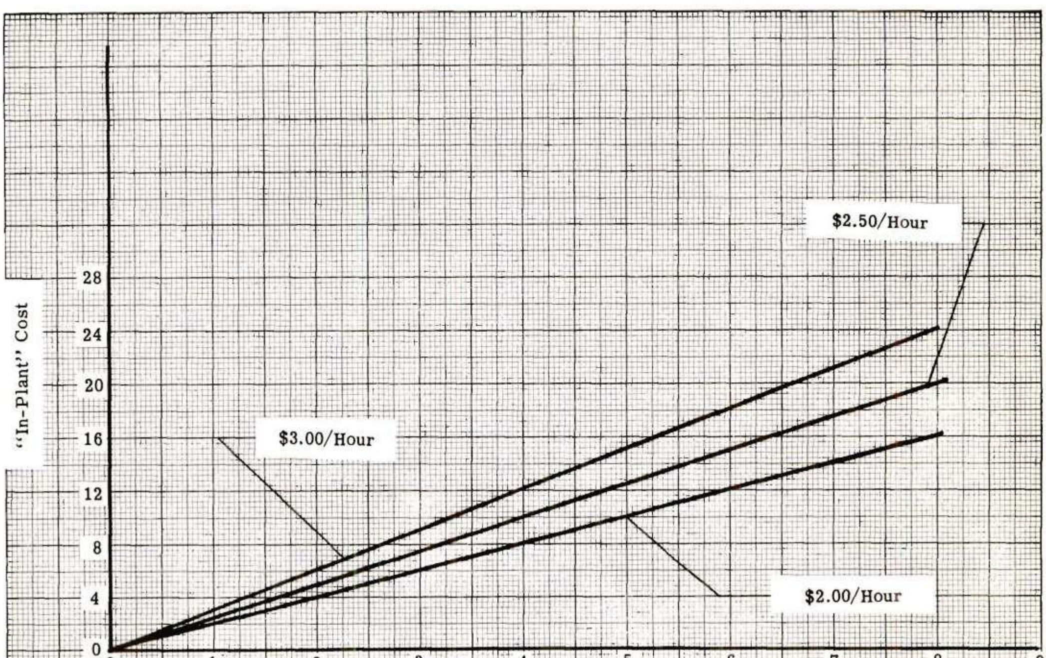
equation

$$X_1' = .890 + .2324\,X_2 - .0293\,X_3 + .1895\,X_4 - .0374\,X_5 + .5921\,X_6$$

to obtain the estimated "in-plant" hours, a correlation of actual "in-plant" hours and estimated "in-plant" hours indicated a coefficient of .969 as shown in Fig. 3.

The test of significance of the correlation coefficient indicated a high degree of significance. A Z-value of 1.697 was obtained while a table of one per cent points of the distribution of Z-values indicates a value of .6540.

The estimated "in-plant" cost can be obtained by multiplying



Comparison of "In-Plant" Cost at Three Different Wage Rates

Fig. 4

the estimated "in-plant" hours by any assumed average hourly wage as shown in Fig. 4. The formal expression used was

$$I' = WX_1$$

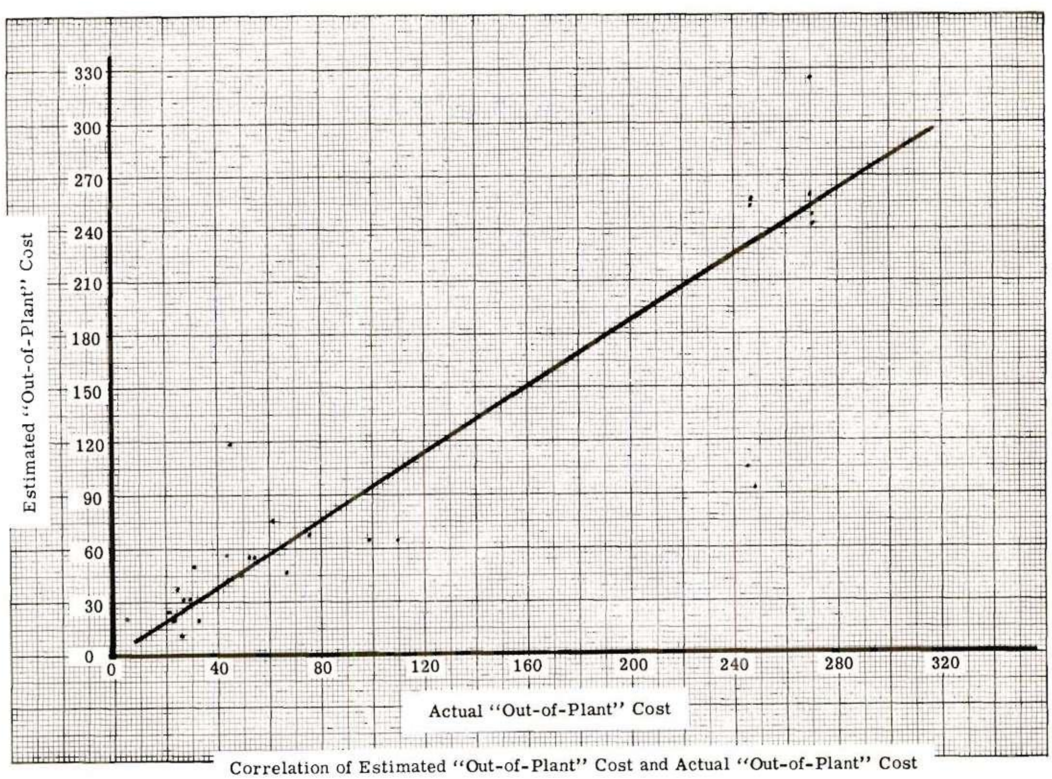
Equations for predicting the estimated "out-of-plant" cost for each of the three methods of manufacture, obtained using the method of least-squares, were:

For conventional milling of gross forgings

$$V' = 2.326\, X_1'^{1.158}$$

For numerically controlled milling of gross forgings

$$V' = 1.943\, X_1'^{2.045}$$



Correlation of Estimated "Out-of-Plant" Cost and Actual "Out-of-Plant" Cost

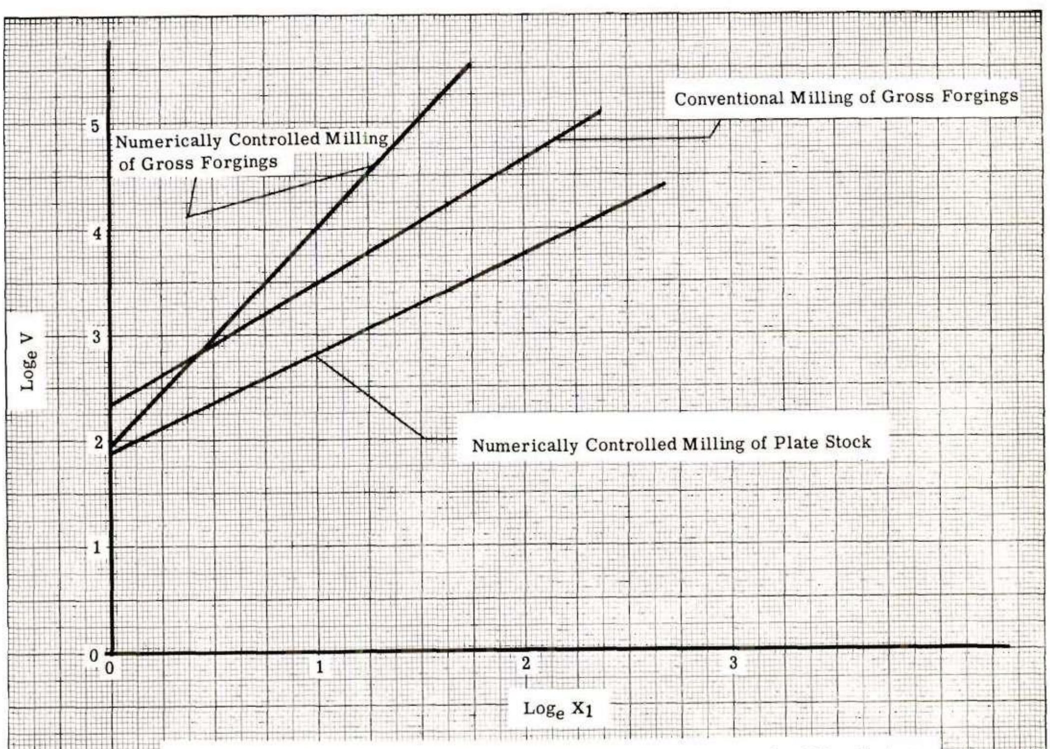
Fig. 5

For numerically controlled milling of plate stock

$$V' = 1.890\ X_1'^{.942}$$

For purposes of comparison, these were expressed linearly and shown in Fig. 5.

Using the above three expressions, correlation coefficients of actual "out-of-plant" cost and estimated "out-of-plant" cost were obtained for each group of parts. These coefficients were .591, .977, and .805 for conventional milling of gross forgings, numerically controlled milling of gross forgings and numerically controlled milling of plate stock, respectively.



Comparison of Predicted "Out-of-Plant" Cost for the Three Methods of Manufacture

Fig. 6

As shown in Fig. 6., an analysis of the pooled estimated "out-of-plant" cost yielded a correlation coefficient of .893.

As shown in Fig. 7., the expression for estimated total cost

$$T' = I' + V'$$

was plotted for each method of manufacture considered.

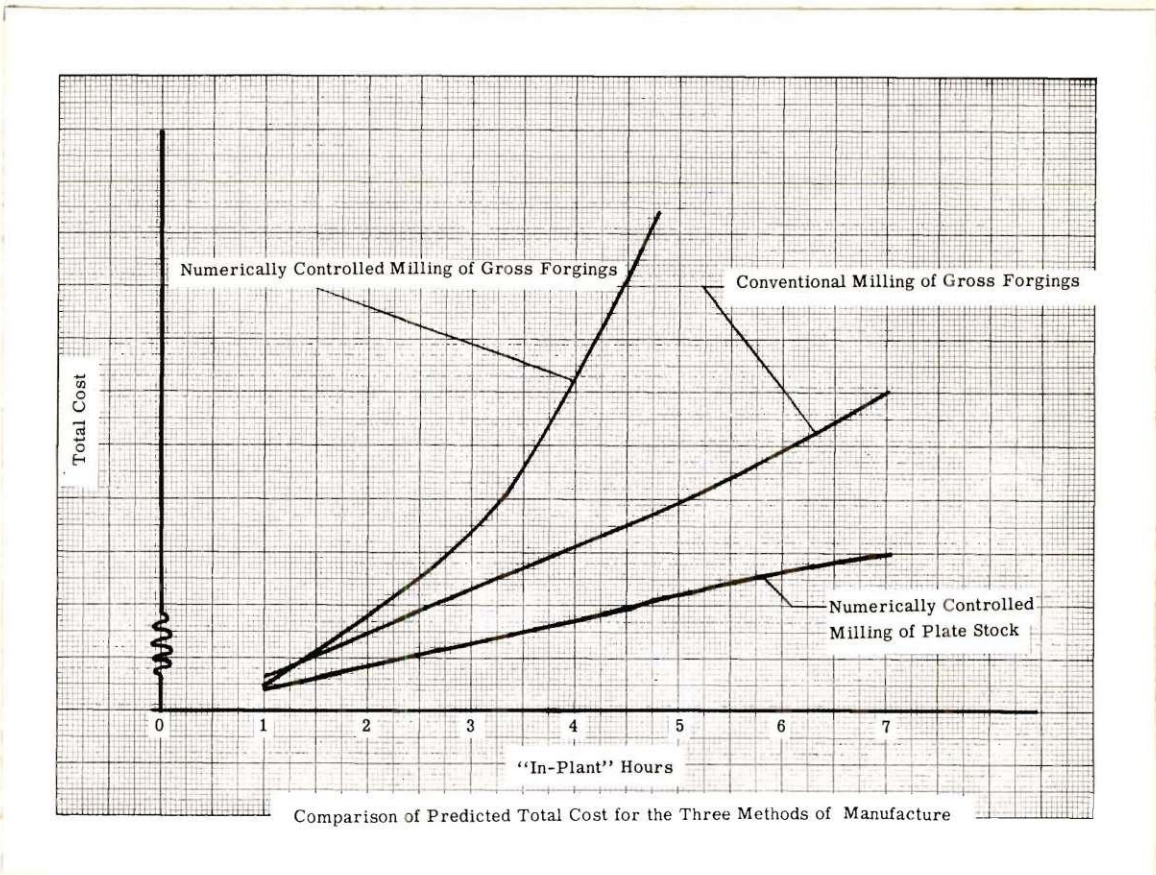
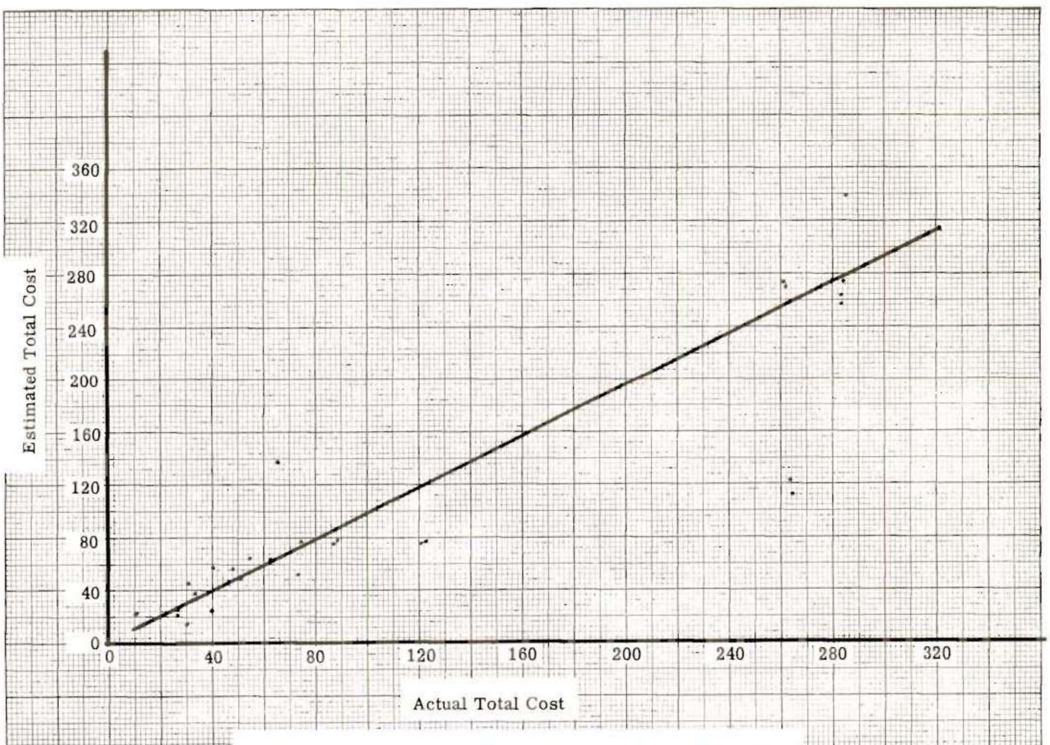


Fig. 7

As shown in Fig. 8, an analysis of the combined total cost yielded a correlation coefficient of .901.



Correlation of Estimated Total Cost and Actual Total Cost

Fig. 8

CHAPTER V

CONCLUSIONS

As stated in Chapter I, it was hypothesized that a decision model for predicting the cost of aluminum airframe detail parts could be developed. For the sample of machined parts investigated, the methods of manufacture included, and the various conditions stated elsewhere in this report, it is concluded that:

(1) A decision model for predicting the cost of aluminum airframe detail parts can be developed.

(2) The number of direct hours expended in the design and making of tools and in producing a finished machined part can be estimated by the use of a regression equation developed from initial engineering information.

(3) Significant initial engineering information which can be used in an analysis to estimate the number of direct hours which will be expended in a given plant to produce a machined detail part is the following: the number of planes in which machining is done, the number of dimensions required on the face of the engineering drawing, the number of different external (non-hole) radii, the number of holes, and the number of different internal (hole) radii.

(4) The estimated number of direct hours which will be expended in a given plant to produce a finished detail part can be used to

estimate the relative costs associated with procurement of material in the form of plate stock or gross forgings.

(5) The total cost to produce a detail part can be estimated by summing the estimated expended hours in the plant, multiplied by an average hourly wage rate, and the estimated costs associated with procurement of material.

(6) When the functional requirements of a detail part can be met by the use of plate stock, milled by numerical control, the cost will be less than machining a gross forging by either conventional manually controlled milling or numerically controlled milling.

(7) When criteria other than cost dictate the use of a forging to make a detail part rather than machining the part from plate stock, numerically controlled milling will cost more than conventional manually controlled milling if the estimated hours per part which will be expended in the plant exceeds a relatively low value. In this investigation a "break-even" point was found to exist at approximately 1.5 "in-plant" hours.

CHAPTER VI

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

During the course of this investigation many related areas of interest were noted but not probed because of insufficient time. Some of these are common to any approach to modeling; others are peculiar to the aircraft industry. However, all may be worth considering when topics in this field are subjected to further investigation.

In developing this decision model it was noted that only cost would be considered as criterion. Obviously, in a production operation time could be even more critical than cost when conformance to certain schedules is required. Therefore, selection of one method of manufacture over another would require only a knowledge of which was faster. When both time and cost are involved the selection of method may be extremely difficult because, in general, the quickest way will not be the least expensive. The problem then is to ascertain just what time is worth. Small production delays may result in eventual delivery delays with customer dissatisfaction resulting. Often it is difficult to appraise just what this customer good will is worth, which fact only adds to the pressure in making wise decisions early in the production schedules.

This model or set of predictor equations was developed from a small sample and only for machined detail parts of 7075 - T6 aluminum alloy. Although the machining index is similar for all aluminum alloys, an obvious investigation is to analyze other alloys. In addition, other classes of parts, such as sheet metal, extrusions, and castings, could be analyzed.

An excellent prospect for investigation is the relation of direct hours expended by Tool Design and Tool Manufacture to Production. In the sample used in this investigation, it was noted that of the total hours expended, approximately 65 per cent were spent by Production. For machined parts which require design of fixtures as well as the building of the fixtures, perhaps this is a good average. But what is the relation for sheet metal parts where many of the tools are built without a formal design being made?

The costs used in this model were direct costs in the sense that they could be related to a specific detail part. Indirect costs, such as Tool Inspection, Quality Control, Transportation, Maintenance, etc., were not included because at present, the only way these costs are recorded is by totaling charges which are not direct, then distributing them to each department on a basis of a percentage of direct hours expended. Including these costs in this model would have been possible but it would only have raised the levels of cost by a constant, and introduced error in the data. Therefore, another needed investigation is to analyze the actual distribution of these indirect costs rather than continuing this blanket application.

It is entirely possible that initial engineering other than that used in this investigation would yield more accurate predictors. Items such as the size of the envelope required to enclose the part in its largest plane, amount of metal to be removed in reducing a gross part to net dimensions, net weight of part, gross weight of part, cross-sectional area, etc., are possible suspect variables.

APPENDIX I

LIST OF SYMBOLS USED

X_1 -- actual hours/part

X_1' -- estimated hours/part

X_2 -- number of planes in which machining is done

L -- partial regression coefficient of X_2

X_3 -- number of dimensions on engineering drawing

D -- partial regression coefficient of X_3

X_4 -- number of different external (non-hole) radii

R -- partial regression coefficient of X_4

X_5 -- number of holes

A -- partial regression coefficient of X_5

X_6 -- number of different internal (hole) radii

B -- partial regression coefficient of X_6

W -- average wage rate (dollars/hour)

V -- actual "out-of-plant" cost/part

V' -- estimated "out-of-plant" cost/part

I -- actual "in-plant" cost/part

I' -- estimated "in-plant" cost/part

T -- actual total cost/part

T' -- estimated total cost/part

APPENDIX IIA

Table 1. Values Used in Multiple Correlation

Part Number	X_1	X_2	X_3	X_4	X_5	X_6
1	2.123	8	49	3	12	2
2	2.123	8	49	3	12	2
3	3.669	13	80	6	41	6
4	3.669	13	80	6	41	6
5	3.106	9	91	5	36	5
6	3.106	9	91	5	36	5
7	4.392	15	82	6	51	6
8	3.360	13	68	5	46	4
9	3.360	13	68	5	46	4
10	7.520	16	151	12	88	13
11	6.852	16	147	11	85	13
12	8.333	28	149	9	68	10
13	8.333	28	149	9	68	10
14	4.995	15	105	8	64	7
15	4.995	15	105	8	64	7
16	3.886	11	96	6	47	6
17	3.886	11	96	6	47	6
18	1.743	4	20	2	14	2
19	1.743	4	20	2	14	2
20	5.123	16	113	7	72	8
21	5.123	16	113	7	72	8
22	4.226	14	87	7	51	6
23	4.226	14	87	7	51	6
24	4.773	15	106	8	61	8
25	4.773	15	106	8	61	8
26	2.139	3	29	2	26	3
27	2.139	3	29	2	26	3
28	5.688	16	133	10	72	10
29	6.546	17	148	10	80	11
30	5.851	16	137	10	75	10
31	5.806	17	141	10	74	11
32	5.874	16	138	10	76	10
33	5.728	17	142	10	70	11
34	2.583	6	56	4	32	3
35	2.496	5	72	4	38	4
36	2.496	5	72	4	38	4
37	1.945	3	36	3	19	2
38	1.945	3	36	3	19	2
39	3.161	7	62	5	21	3
40	8.440	24	172	14	105	15
41	8.440	24	172	14	105	15
Totals:	180.715	521	3883	276	2124	277

Table 1. (Cont.)

Part Number	X_1^2	X_2^2	X_3^2	X_4^2	X_5^2	X_6^2
1	4.507	64	2401	9	144	4
2	4.507	64	2401	9	144	4
3	13.461	169	6400	36	1681	36
4	13.461	169	6400	36	1681	36
5	9.647	81	8281	25	1296	25
6	9.647	81	8281	25	1296	25
7	19.289	225	6724	36	2601	36
8	11.289	169	4624	25	2116	16
9	11.289	169	4624	25	2116	16
10	56.550	256	22801	144	7744	169
11	49.949	256	21609	121	7225	169
12	69.438	784	22201	81	4624	100
13	69.438	784	22201	81	4624	100
14	24.950	225	11025	64	4096	49
15	24.950	225	11025	64	4096	49
16	15.100	121	9216	36	2209	36
17	15.100	121	9216	36	2209	36
18	3.038	16	400	4	196	4
19	3.038	16	400	4	196	4
20	26.245	256	12769	49	5184	64
21	26.245	256	12769	49	5184	64
22	17.859	196	7569	49	2601	36
23	17.859	196	7569	49	2601	36
24	22.781	225	11236	64	3721	64
25	22.781	225	11236	64	3721	64
26	4.575	9	841	4	676	9
27	4.575	9	841	4	676	9
28	32.353	256	17689	100	5184	100
29	42.850	289	21904	100	6400	121
30	34.234	256	18769	100	5625	100
31	33.709	289	19881	100	5476	121
32	34.503	256	19044	100	5776	100
33	32.809	289	20164	100	4900	121
34	6.671	36	3136	16	1024	9
35	6.230	25	5184	16	1444	16
36	6.230	25	5184	16	1444	16
37	3.783	9	1296	9	361	4
38	3.783	9	1296	9	361	4
39	9.991	49	3844	25	441	9
40	71.233	576	29584	196	11025	225
41	71.233	576	29584	196	11025	225
TOTALS:	958.180	8307	441,619	2276	135,144	2431

Table 1. (Cont.)

Part Number	X_1X_2	X_1X_3	X_1X_4	X_1X_5	X_1X_6
1	16.984	104.027	6.369	25.476	4.246
2	16.984	104.027	6.369	25.476	4.246
3	47.697	293.520	22.014	150.429	22.014
4	47.697	293.520	22.014	150.429	22.014
5	27.954	282.646	15.530	111.816	15.530
6	27.954	282.646	15.530	111.816	15.530
7	65.880	360.144	26.352	223.992	26.352
8	43.680	228.480	16.800	154.560	13.440
9	43.680	228.480	16.800	154.560	13.440
10	120.320	1135.520	90.240	661.760	97.760
11	109.632	1007.244	75.372	582.420	89.076
12	233.324	1241.617	74.997	566.644	83.330
13	233.324	1241.617	74.997	566.644	83.330
14	74.925	524.475	39.960	319.680	34.965
15	74.925	524.475	39.960	319.680	34.965
16	42.746	373.056	23.316	182.642	23.316
17	42.746	373.056	23.316	182.642	23.316
18	6.972	34.860	3.486	24.402	3.986
19	6.972	34.860	3.486	24.402	3.986
20	81.968	578.899	35.861	368.856	40.984
21	81.968	578.899	35.861	368.856	40.984
22	59.164	367.662	29.582	215.526	25.356
23	59.164	367.662	29.582	215.526	25.356
24	71.595	505.938	38.184	291.153	38.184
25	71.595	505.938	38.184	291.153	38.184
26	6.417	62.031	4.278	55.614	6.417
27	6.417	62.031	4.278	55.614	6.417
28	91.008	756.504	56.880	409.536	56.880
29	111.282	968.808	65.460	523.680	72.006
30	93.616	801.587	58.510	438.825	58.510
31	98.702	818.646	58.060	429.644	63.866
32	93.984	810.612	58.740	446.424	58.740
33	97.376	813.376	57.280	400.960	63.008
34	15.498	144.648	10.332	82.656	7.749
35	12.480	179.712	9.984	94.848	9.984
36	12.480	179.712	9.984	94.848	9.984
37	5.835	70.020	5.835	36.955	3.890
38	5.835	70.020	5.835	36.955	3.890
39	22.127	195.982	15.805	66.381	9.483
40	202.560	1451.680	118.160	886.200	126.600
41	202.560	1451.680	118.160	886.200	126.600
Totals	2788.027	20,411.317	1461.743	11,235.960	1506.959

Table 1. (Cont.)

Part Number	X_2X_3	X_2X_4	X_2X_5	X_2X_6	X_3X_4
1	392	24	96	16	147
2	392	24	96	16	147
3	1040	78	533	78	480
4	1040	78	533	78	480
5	819	45	324	45	455
6	819	45	324	45	455
7	1230	90	765	90	492
8	884	65	598	52	340
9	884	65	598	52	340
10	2416	192	1408	208	1812
11	2352	176	1360	208	1617
12	4172	252	1904	280	1341
13	4172	252	1904	280	1341
14	1575	120	960	105	840
15	1575	120	960	105	840
16	1056	66	517	66	576
17	1056	66	517	66	576
18	80	8	56	8	40
19	80	8	56	8	40
20	1808	112	1152	128	791
21	1808	112	1152	128	791
22	1218	98	714	84	609
23	1218	98	714	84	609
24	1590	120	915	120	848
25	1590	120	915	120	848
26	87	6	78	9	58
27	87	6	78	9	58
28	2128	160	1152	100	1330
29	2516	160	1360	176	1480
30	3192	160	1200	160	1370
31	2397	160	1258	176	1410
32	2208	160	1216	160	1380
33	2414	160	1190	176	1420
34	336	24	192	18	224
35	360	20	190	20	288
36	360	20	190	20	288
37	108	9	57	6	108
38	108	9	57	6	108
39	434	35	147	21	310
40	4128	336	2520	360	2408
41	4128	336	2520	360	2408
Totals	59,257	4195	32,476	4307	31,503

Table 1. (Cont.)

Part Number	X_3X_5	X_3X_6	X_4X_5	X_4X_6	X_5X_6
1	588	98	36	6	24
2	588	98	36	6	24
3	3280	480	246	36	246
4	3280	480	246	36	246
5	3276	455	180	25	180
6	3276	455	180	25	180
7	4182	492	306	36	306
8	3128	272	230	20	184
9	3128	272	230	20	184
10	13,288	1963	1056	156	1144
11	12,495	1911	935	143	1105
12	10,132	1490	612	90	680
13	10,132	1490	612	90	680
14	6720	735	512	56	448
15	6720	735	512	56	448
16	4512	576	282	36	282
17	4512	576	282	36	282
18	280	40	28	4	28
19	280	40	28	4	28
20	8136	904	504	56	576
21	8136	904	504	56	576
22	4437	522	357	42	306
23	4437	522	357	42	306
24	6466	848	488	64	488
25	6466	848	488	64	488
26	754	87	52	6	78
27	754	87	52	6	78
28	9576	1330	720	100	720
29	11,940	1628	800	110	880
30	10,275	1370	750	100	750
31	10,434	1551	740	110	814
32	10,488	1380	760	100	760
33	9940	1562	700	110	770
34	1792	168	128	12	96
35	2736	288	152	16	152
36	2736	288	152	16	152
37	684	72	57	6	38
38	684	72	57	6	38
39	1302	186	105	15	63
40	18,060	2580	1470	210	1575
41	18,060	2580	1470	210	1575
Totals	241,990	32,435	17,412	2338	17,978

APPENDIX IIB

Table 2. Values Used in Correlation of X_1 and X_1'

Part Number	X_1	X_1^2	X_1'	$X_1'^2$	X_1X_1'
1	2.123	4.507	2.618	6.853	5.558
2	2.123	4.507	2.618	6.853	5.558
3	3.669	13.461	4.723	22.306	17.328
4	3.669	13.461	4.723	22.306	17.328
5	3.106	9.647	2.876	8.271	8.932
6	3.106	9.647	2.876	8.271	8.932
7	4.392	19.289	4.756	22.619	20.888
8	3.360	11.289	3.514	12.348	11.807
9	3.360	11.289	3.514	12.348	11.807
10	7.520	56.550	6.864	47.114	51.617
11	6.852	46.949	7.539	56.836	51.657
12	8.333	69.438	8.115	65.853	67.222
13	8.333	69.438	8.115	65.853	67.222
14	4.995	24.950	4.567	20.857	22.812
15	4.995	24.950	4.567	20.857	22.812
16	3.886	15.100	3.566	12.716	13.857
17	3.886	15.100	3.566	12.716	13.857
18	1.743	3.038	2.273	5.166	3.961
19	1.743	3.038	2.273	5.166	3.961
20	5.123	26.245	4.668	21.790	23.914
21	5.123	26.245	4.668	21.790	23.914
22	4.226	17.859	4.565	20.839	19.291
23	4.226	17.859	4.565	20.839	19.291
24	4.773	22.781	5.242	27.478	25.020
25	4.773	22.781	5.242	27.478	25.020
26	2.139	4.575	1.921	3.690	4.109
27	2.139	4.575	1.921	3.690	4.109
28	5.688	32.353	5.836	34.058	33.195
29	6.546	42.850	5.920	35.046	38.752
30	5.851	34.234	5.555	30.858	32.502
31	5.806	33.709	6.350	40.322	36.868
32	5.874	34.503	5.539	30.680	32.536
33	5.728	32.809	5.470	29.920	31.332
34	2.583	6.671	1.982	3.928	5.119
35	2.496	6.230	1.648	2.715	4.113
36	2.496	6.230	1.648	2.715	4.113
37	1.945	3.783	1.575	2.480	3.063
38	1.945	3.783	1.575	2.480	3.063
39	3.161	9.991	2.638	6.959	8.338
40	8.440	71.233	9.035	81.631	76.255
41	8.440	71.233	9.035	81.631	76.255
Totals	180.715	958.180	180.261	968.326	968.326

APPENDIX IIC

Table 3. Values Used in Correlation of V and V'

Part Number	V	V^2	V'	V'^2	VV'
1	21.78	474.368	24.48	599.270	533.174
2	21.78	474.368	24.48	599.270	533.174
3	50.01	2501.000	46.12	2127.054	2306.461
4	50.01	2501.000	46.12	2127.054	2306.461
5	25.10	630.000	38.04	1447.041	954.804
6	25.10	630.000	38.04	1447.041	954.804
7	44.52	1982.030	56.20	3158.440	2502.024
8	44.48	1978.470	41.65	1734.722	1852.592
9	44.48	1978.470	41.65	1734.722	1852.592
10	245.48	60,260.430	106.30	11,299.690	26,094.524
11	248.52	61,762.190	95.07	9038.304	23,626.796
12	45.28	2050.278	118.88	14,132.454	5382.886
13	45.28	2050.278	118.88	14,132.454	5382.886
14	109.99	12,097.800	65.96	4350.721	7254.940
15	110.96	12,312.121	65.96	4350.721	7318.921
16	31.93	1019.524	49.36	2436.409	1576.064
17	31.93	1019.524	49.36	2436.409	1576.064
18	23.48	551.310	19.45	378.302	456.686
19	23.48	551.310	19.45	378.302	456.686
20	76.76	5892.097	67.09	4501.068	5149.828
21	76.76	5892.097	67.09	4501.068	5149.828
22	53.58	2870.816	54.31	2949.576	2909.929
23	53.58	2870.816	54.31	2949.576	2909.929
24	76.76	5892.097	62.55	3912.502	4801.338
25	76.76	5892.097	62.55	3912.502	4801.338
26	29.08	845.646	33.02	1090.320	960.221
27	28.02	785.120	33.02	1090.320	925.220
28	270.70	73,278.490	244.25	59,658.062	66,118.475
29	270.54	73,191.891	325.38	105,872.144	88,028.305
30	247.36	61,188.969	258.48	66,811.910	63,937.612
31	247.20	61,107.840	254.18	64,607.472	62,833.296
32	270.70	73,278.490	260.60	67,912.360	70,544.442
33	270.54	73,191.891	248.65	61,826.822	67,269.771
34	67.70	4583.290	48.55	2356.131	3281.304
35	5.16	26.625	19.20	368.640	99.072
36	5.16	26.625	19.20	368.640	99.072
37	26.17	684.868	12.93	161.187	338.378
38	26.17	684.868	12.93	161.187	338.378
39	33.07	1093.624	19.60	384.160	648.172
40	54.75	2997.562	54.50	2970.250	2983.875
41	54.75	2997.562	54.50	2970.250	2983.875
Totals	3564.86	626,095.852	3332.33	539,286.527	550,033.197

APPENDIX IID

Table 4. Values Used in Correlation of T and T'

Part Number	T	T^2	T'	T'^2	T T'
1	27.09	733.868	31.03	962.860	840.602
2	27.09	733.868	31.03	962.860	840.602
3	59.18	3502.272	57.93	3355.884	3428.297
4	59.18	3502.272	57.93	3355.884	3428.297
5	32.87	1080.436	45.23	2045.752	1486.710
6	32.87	1080.436	45.23	2045.752	1486.710
7	55.50	3080.250	68.09	4636.248	3778.995
8	52.88	2796.294	50.44	2544.193	2667.267
9	52.88	2796.294	50.44	2544.193	2667.267
10	264.28	69,843.918	123.46	15,242.371	32,628.008
11	265.65	70,569.922	113.92	12,977.766	30,262.848
12	66.11	4370.532	139.17	19,368.288	9200.528
13	66.11	4370.532	139.17	19,368.288	9200.528
14	122.48	15,001.350	77.38	5987.664	9477.502
15	123.45	15,239.902	77.38	5987.664	9552.561
16	41.65	1734.722	58.28	3396.558	2427.362
17	41.65	1734.722	58.28	3396.558	2427.362
18	27.84	775.065	25.13	631.516	699.619
19	27.84	775.065	25.13	631.516	699.619
20	89.57	8022.784	78.76	6203.137	7054.533
21	89.57	8022.784	78.76	6203.137	7054.533
22	64.15	4115.222	65.72	4319.118	4215.938
23	64.15	4115.222	65.72	4319.118	4215.938
24	88.69	7865.916	75.66	5724.435	6710.285
25	88.69	7865.916	75.66	5724.435	6710.285
26	34.46	1187.491	37.82	1430.352	1303.277
27	34.46	1187.491	37.82	1430.352	1303.277
28	284.92	81,179.406	258.84	66,998.145	73,748.692
29	286.91	82,317.348	340.18	115,722.432	97,601.043
30	261.99	68,638.760	272.37	74,185.416	71,358.216
31	261.72	68,497.358	270.06	72,932.403	70,680.103
32	285.39	81,447.452	274.45	75,322.802	78,325.285
33	284.86	81,145.521	262.33	68,817.028	74,727.323
34	74.16	5499.705	53.51	2863.320	3968.301
35	11.40	129.960	23.32	543.822	265.848
36	11.40	129.960	23.32	543.822	265.848
37	31.03	962.860	16.87	284.596	523.476
38	31.03	962.860	16.87	284.596	523.476
39	40.97	1678.540	26.20	686.440	1073.414
40	75.85	5753.222	77.09	5942.868	5847.276
41	75.85	5753.222	77.09	5942.868	5847.276
Totals	4017.82	730,200.720	3783.07	635,866.457	650,524.327

APPENDIX IIIA

SAMPLE COMPUTATIONS FOR CORRELATION OF X_1 AND X_3

Covariance of X_1X_3

$$= 1/N\Sigma X_1X_3 - (\Sigma X_1/N)(\Sigma X_3/N)$$

$$= 497.837 - (4.907)(94.707)$$

$$= 80.464$$

Variance of X_1

$$= 1/N\Sigma X_1^{\,2} - (\Sigma X_1/N)^2$$

$$= 23.370 - (4.407)^2$$

$$= 3.949$$

Variance of X_3

$$= 1/N\Sigma X_3^{\,2} - (\Sigma X_3/N)^2$$

$$= 10{,}771.195 - (94.707)^2$$

$$= 1{,}801.780$$

Correlation Coefficient $R_{X_1X_3} = \dfrac{\text{Covariance}}{\sqrt{\text{Variance } X_1 \times \text{Variance } X_3}}$

$$= \frac{80.464}{\sqrt{(3.949)(1{,}801.780)}}$$

$$= .954$$

APPENDIX IIIB

SAMPLE COMPUTATIONS FOR EQUATIONS USED IN OBTAINING THE REGRESSION EQUATION

Using the notation of Ezekiel, where

$X =$ observed value

$x =$ corrected value

$n =$ number of observations

$M =$ mean of observed values

and L, D, R, A, B, are partial regression coefficients

then

$$\Sigma(x_1^2) = \Sigma(X_1^2) - n(M_1^2)$$
$$= 958.180 - (41)(4.407)^2 = 161.919$$
$$\Sigma(x_2^2) = \Sigma(X_2^2) - n(M_2^2)$$
$$= 8,307.000 - (41)(12.707)^2 = 1686.853$$
$$\Sigma(x_3^2) = \Sigma(X_3^2) - n(M_3^2)$$
$$= 441,619.000 - (41)(94.707)^2 = 73,872.985$$
$$\Sigma(x_4^2) = \Sigma(X_4^2) - n(M_4^2)$$
$$= 2276.000 - (41)(6.731)^2 = 418.454$$
$$\Sigma(x_5^2) = \Sigma(X_5^2) - n(M_5^2)$$
$$= 135,144.000 - (41)(51.804)^2 = 25,114.186$$
$$\Sigma(x_6^2) = \Sigma(X_6^2) - n(M_6^2)$$
$$= 2,431.000 - (41)(6.756)^2 = 559.637$$

$$\Sigma(x_1x_2) = \Sigma(X_1X_2) - n(M_1M_2)$$
$$= 2{,}788.027 - (41)(4.407)(12.707) = 492.068$$

$$\Sigma(x_1x_3) = \Sigma(X_1X_3) - n(M_1M_3)$$
$$= 20{,}411.317 - (41)(4.407)(94.707) = 3{,}299.024$$

$$\Sigma(x_1x_4) = \Sigma(X_1X_4) - n(M_1M_4)$$
$$= 1{,}461.743 - (41)(4.407)(6.731) = 245.560$$

$$\Sigma(x_1x_5) = \Sigma(X_1X_5) - n(M_1M_5)$$
$$= 11{,}235.960 - (41)(4.407)(51.804) = 1{,}875.660$$

$$\Sigma(x_1x_6) = \Sigma(X_1X_6) - n(M_1M_6)$$
$$= 1{,}506.959 - (41)(4.407)(6.756) = 286.266$$

$$\Sigma(x_2x_3) = \Sigma(X_2X_3) - n(M_2M_3)$$
$$= 59{,}257.000 - (41)(12.707)(94.707) = 9{,}922.892$$

$$\Sigma(x_2x_4) = \Sigma(X_2X_4) - n(M_2M_4)$$
$$= 4{,}195.000 - (41)(12.707)(6.731) = 688.270$$

$$\Sigma(x_2x_5) = \Sigma(X_2X_5) - n(M_2M_5)$$
$$= 32{,}476.000 - (41)(12.707)(51.804) = 5{,}486.807$$

$$\Sigma(x_2x_6) = \Sigma(X_2X_6) - n(M_2M_6)$$
$$= 4{,}307.000 - (41)(12.707)(6.756) = 787.232$$

$$\Sigma(x_3x_4) = \Sigma(X_3X_4) - n(M_3M_4)$$
$$= 31{,}503.000 - (41)(94.707)(6.731) = 5{,}366.648$$

$$\Sigma(x_3x_5) = \Sigma(X_3X_5) - n(M_3M_5)$$
$$= 241{,}990.000 - (41)(94.707)(51.804) = 40{,}835.759$$

$$\Sigma(x_3x_6) = \Sigma(X_3X_6) - n(M_3M_6)$$
$$= 32{,}435.000 - (41)(94.707)(6.756) = 6{,}201.560$$

$$\Sigma(x_4x_5) = \Sigma(X_4X_5) - n(M_4M_5)$$
$$= 17{,}412.000 - (41)(6.731)(51.804) = 3{,}115.628$$

$$\Sigma(x_4x_6) = \Sigma(X_4X_6) - n(M_4M_6)$$
$$= 2{,}338.000 - (41)(6.731)(6.756) = 473.566$$
$$\Sigma(x_5x_6) = \Sigma(X_5X_6) - n(M_5M_6)$$
$$= 17{,}978.000 - (41)(51.804)(6.756) = 3{,}628.533$$
$$\Sigma(x_1x_2) = \Sigma(x_2^{\,2})L + \Sigma(x_2x_3)D + \Sigma(x_2x_4)R + \Sigma(x_2x_5)A + \Sigma(x_2x_6)B$$
$$492.068 = 1{,}686.853L + 9{,}922.892D + 688.270R + 5{,}486.807A + 787.232B$$
$$\Sigma(x_1x_3) = \Sigma(x_2x_3)L + \Sigma(x_3^{\,2})D + \Sigma(x_3x_4)R + \Sigma(x_3x_5)A + \Sigma(x_3x_6)B$$
$$3{,}299.024 = 9{,}922.892L + 73{,}872.985D + 5{,}366.648R + 40{,}835.759A + 6{,}201.560B$$
$$\Sigma(x_1x_4) = \Sigma(x_2x_4)L + \Sigma(x_3x_4)D + \Sigma(x_4^{\,2})R + \Sigma(x_4x_5)A + \Sigma(x_4x_6)B$$
$$245.560 = 688.270L + 5{,}366.648D + 418.454R + 3{,}115.628A + 473.566B$$
$$\Sigma(x_1x_5) = \Sigma(x_2x_5)L + \Sigma(x_3x_5)D + \Sigma(x_4x_5)R + \Sigma(x_5^{\,2})A + \Sigma(x_5x_6)B$$
$$1{,}875.660 = 5{,}486.807L + 40{,}835.759D + 3{,}115.628R + 25{,}114.186A + 3{,}628.533B$$
$$\Sigma(x_1x_6) = \Sigma(x_2x_6)L + \Sigma(x_3x_6)D + \Sigma(x_4x_6)R + \Sigma(x_5x_6)A + \Sigma(x_6^{\,2})B$$
$$286.266 = 787.232L + 6{,}201.560D + 473.566R + 3{,}628.533A + 559.637B$$

Solution of five simultaneous equations by IBM 704 computer yielded these partial regression coefficients:

$L = .2324$

$D = -.0293$

$R = .1895$

$A = -.0374$

$B = .5921$

Solution for constant of regression equation:

$$a_{1.23456} = M_1 - LM_2 - DM_3 - RM_4 - AM_5 - BM_6$$
$$= 4.407 - 2.953 + 2.774 - 1.275 + 1.937 - 4.000$$
$$= .890$$

Final regression equation used to estimate "in-plant" hours:

$$X'_{1.23456} = .890 + .2324X_2 - .0293X_3 + .1895X_4 - .0374X_5 + .5921X_6$$

APPENDIX IIIC

SAMPLE COMPUTATIONS FOR MULTIPLE CORRELATION ANALYSIS AND TEST OF SIGNIFICANCE

$$R^2 = \frac{L(\Sigma x_1 x_2) + D(\Sigma x_1 x_3) + R(\Sigma x_1 x_4) + A(\Sigma x_1 x_5) + B(\Sigma x_1 x_6)}{(\Sigma x_1^{\ 2})}$$

Where R = correlation coefficient

L, D, R, A, B, are partial regression coefficients

$$= \frac{798.932}{958.190}$$

$$= .833$$

Uncorrected for sample size,

$$R = .913$$

Then,

$$r^2 = 1 - (1 - r^2)(n - 1/n - m)$$

Where n = number of observations in the sample

m = number of constants in the regression equation

$$= 1 - (1 - .833)(41 - 1)/(41 - 6)$$

$$= .810$$

Corrected for sample size,

$$r = .900$$

Testing the corrected correlation coefficient for significance,

$$Z = 1/2 \log_e \frac{r^2}{1 - r^2} \times \frac{n - m}{m - 1}$$

$$Z = 1/2 \log_e (.81/.19)(35/5)$$

$$= \frac{3.3945}{2}$$

$$= 1.697$$

A table of Z-values at the one per cent level indicates a value of .6540 for n - m = 30. Therefore, r is significant since Z = 1.697 > .6540.

APPENDIX IIID

SAMPLE COMPUTATIONS FOR CORRELATION OF X_1 AND X_1'

Covariance of X_1 and X_1'

$$= 1/N\Sigma X_1X_1' - (\Sigma X_1/N)(\Sigma X_1'/N)$$

$$= 23.367 - (4.407)(4.396)$$

$$= 3.994$$

Variance of X_1

$$= 1/N\Sigma X_1^2 - (\Sigma X_1/N)^2$$

$$= 23.370 - (4.407)^2$$

$$= 3.949$$

Variance of X_1'

$$= 1/N\Sigma X_1'^2 - (\Sigma X_1'/N)^2$$

$$= 23.617 - (4.396)^2$$

$$= 4.293$$

Correlation Coefficient $R_{X_1X_1'} = \dfrac{\text{Covariance}}{\sqrt{\text{Variance } X_1 \times \text{Variance } X_1'}}$

$$= \frac{3.994}{\sqrt{3.949 \times 4.293}}$$

$$= .954$$

APPENDIX IIIE

SAMPLE COMPUTATIONS FOR CORRELATION OF V AND V'

Covariance of V and V'

$$= 1/N\Sigma VV' \; - \; (\Sigma V/N)(\Sigma V'/N)$$

$$= 13,415.443 \; - \; (86.954)(81.276)$$

$$= 6,348.902$$

Variance of V

$$= 1/N\Sigma V^2 \; - \; (\Sigma V/N)^2$$

$$= 15,270.635 \; - \; (86.945)^2$$

$$= 7,711.202$$

Variance of V'

$$= 1/N\Sigma V'^2 \; - \; (\Sigma V'/N)^2$$

$$= 13,153.329 \; - \; (81.276)^2$$

$$= 6,547.541$$

Correlation Coefficient $R_{VV'} = \dfrac{\text{Covariance}}{\sqrt{\text{Variance V x Variance V'}}}$

$$= \frac{6,348.902}{\sqrt{7,711.202 \times 6,547.541}}$$

$$= .893$$

APPENDIX IIIF

SAMPLE COMPUTATIONS FOR CORRELATION OF T AND T'

Covariance of T and T'

$$= 1/N\Sigma TT' - (\Sigma T/N)(\Sigma T'/N)$$

$$= 15{,}866.447 - (97.995)(92.270)$$

$$= 6{,}824.449$$

Variance of T

$$= 1/N\Sigma T^2 - (\Sigma T/N)^2$$

$$= 17{,}809.773 - (97.995)^2$$

$$= 8{,}206.753$$

Variance of T'

$$= 1/N\Sigma T'^2 - (\Sigma T'/N)^2$$

$$= 15{,}508.937 - (92.270)^2$$

$$= 6{,}995.185$$

$$\text{Correlation Coefficient } R_{TT'} = \frac{\text{Covariance}}{\sqrt{\text{Variance T x Variance T'}}}$$

$$= \frac{6{,}824.449}{\sqrt{8{,}206.753 \times 6{,}995.185}}$$

$$= .901$$

APPENDIX IV

DEVELOPMENT OF "OUT-OF-PLANT" COSTS

For Gross Forgings

As mentioned in Chapter II, the files of the Purchasing Division was the source of data pertaining to the actual "out-of-plant" costs for each part. This card file shows the date of procurement, number of parts procured, and cost per part procured. For each gross forging in the sample the total cost of parts purchased was divided by the total number of parts purchased to obtain the actual material cost per part. The card file also indicates the cost paid for the set of dies required to form the forging. This cost was divided by the number of parts that were estimated to be required over the design life of the part (as obtained from the Master Record Tool Control files). There is an additional cost per lot of forgings ordered for setting up the dies. This set-up charge is usually established at the time the dies are ordered and is a fixed charge regardless of the number of pieces ordered in subsequent lots. Some of the detail parts included in the sample had already completed their estimated design life. From the history of these parts an average number of lots ordered was obtained. Thus the set-up cost per part was the set-up charge per lot times the average number of lots per estimated number of parts. The sum of these three costs per part, material, die, and set-up, was used as the actual "out-of-plant" cost per part.

Example

Part number 25

Material cost/part	\$50.36
Cost of dies/estimated number of parts	14.56
Set-up cost/lot x $\frac{\text{average number of lots}}{\text{estimated number of parts}}$	
\$592.00 x 4/200	11.84
Total actual "out-of-plant" cost/part	\$76.76

Note: For gross forgings, the "out-of-plant" cost does not include any transportation costs, which, as shown in Appendix V, can be an appreciable cost/part.

For Plate Stock

For the nine detail parts of the sample that are made from plate stock, the "out-of-plant" cost/part was the same as the material cost per part since there are no die costs or set-up costs. Any plate stock over .250 inches is considered as a "special" order and is procured on a mill run basis. Therefore, the material cost is developed by using a price for a base quantity plus an extra price dependent upon the quantity. At present, this base quantity is 30 thousand pounds. The quantity requirements for plate of the various thicknesses included in the sample are not high, therefore the quantity ordered was never enough to take advantage of quantity prices.

Pricing Schedule

thickness (inches)	pounds/square foot	base price on 30 thousand pounds
.250	3.64	\$0.584
.312	4.55	0.584
.500	7.27	0.584
.750	10.91	0.584

Quantity Extra

pounds	additional price/pound
2000 - 4999	$0.055
3000 - 9999	0.030
10000 - 19999	0.008
20000 - 29999	0.004
30000 -	0.000

Example

Part number 39

Thickness of stock is .250 inches.

Area of stock for part is 28 by 73 inches.

Ordered in quantities of less than 2000 pounds, cost of material is \$0.584 + \$0.055 = \$0.639/pound.

Total actual "out-of-plant" cost/part is

$$\frac{(28 \times 73)}{144} \times 3.64 \times \$0.639 = \$33.07$$

Note: For plate stock, this "out-of-plant" cost does include cost of transportation as is the custom of the industry.

APPENDIX V

TYPICAL TRANSPORTATION COSTS

In general, gross forgings are shipped by truck. Vendors of various forgings included in the sample are located as far away as California and as near as Ohio. Listed below are several cities where vendors are located and the charges for truck shipments to Atlanta.

City	Dollars/Hundred Pounds	
	Less than 2000	More than 2000
Adrian, Michigan	3.16	3.16
Buffalo, New York	3.93	3.66
Cleveland, Ohio	3.11	3.11
Erie, Pennsylvania	3.78	3.51
Fort Worth, Texas	3.83	3.60
West Cheshire, Connecticut	4.23	3.96
Worcester, Massachusetts	4.34	4.06

Example

For part number 28

Gross forging weight is 41.8 pounds.

Assumed shipment of 60 parts would weigh 2508 pounds.

Assumed packing weight of 10% would be 250 pounds.

Total weight would be 2758 pounds.

Vendor is in Adrian, Michigan.

Cost of transportation for shipment would be

27.58 x 3.16 = \$86.85 or \$1.45/part.

APPENDIX VI

TYPICAL MECHANICAL PROPERTIES OF 7075-T6 ALUMINUM ALLOY

Strength ultimate psi	Strength yield psi	Per Cent Elongation in 2" 1/2" dia.	Brinell # 500 kg load 10 mm ball	Shearing Strength psi
83,000	73,000	11	150	48,000

TYPICAL CHEMICAL COMPOSITION OF 7075-T6 ALUMINUM ALLOY BY PER CENT

Silicon	0.60	Magnesium	2.10-2.00
Iron	0.70	Chromium	0.18-0.40
Copper	1.20-2.00	Zinc	5.10-6.10
Manganese	0.30	Titanium	0.20

Note: T6--Solution heat treatment followed by artificial aging.

APPENDIX VII

TYPICAL CONVENTIONAL MANUALLY CONTROLLED MILLING MACHINES

1. Kearney and Trecker Model #5CSM, Knee type, 52 in. Table travel, 50/25 Hp, Automatic cycle.
2. Kearney and Trecker Model #4HS, Knee type, 42 in. Table travel, 3440 and 6990 RPM, Automatic cycle.
3. Fritz-Werner, Knee type, 44 in. Table travel, 12 Hp, Semi-Universal head.
4. Cincinnati Model 28-120, Duplicating, 360 degree profiling, 28 in. by 120 in. Travel, 20 Hp.

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